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Situation Awareness Recovery

Daniel Gartenberg, George Mason University, Fairfax, Virginia, **Leonard Breslow**, Naval Research Laboratory, Washington, DC, **J. Malcolm McCurry**, ITT Exelis, McLean, Virginia, and **J. Greg Trafton**, Naval Research Laboratory, Washington, DC

Objective: We describe a novel concept, situation awareness recovery (SAR), and we identify perceptual and cognitive processes that characterize SAR.

Background: Situation awareness (SA) is typically described in terms of perceiving relevant elements of the environment, comprehending how those elements are integrated into a meaningful whole, and projecting that meaning into the future. Yet SA fluctuates during the time course of a task, making it important to understand the process by which SA is recovered after it is degraded.

Method: We investigated SAR using different types of interruptions to degrade SA. In Experiment 1, participants watched short videos of an operator performing a supervisory control task, and then the participants were either interrupted or not interrupted, after which SA was assessed using a questionnaire. In Experiment 2, participants performed a supervisory control task in which they guided vehicles to their respective targets and either experienced an interruption, during which they performed a visual search task in a different panel, or were not interrupted.

Results: The SAR processes we identified included shorter fixation durations, increased number of objects scanned, longer resumption lags, and a greater likelihood of refixating on objects that were previously looked at.

Conclusions: We interpret these findings in terms of the memory-for-goals model, which suggests that SAR consists of increased scanning in order to compensate for decay, and previously viewed cues act as associative primes that reactivate memory traces of goals and plans.

Keywords: attention, supervisory control, eye movements, memory for goals, situation awareness

Address correspondence to Daniel Gartenberg, George Mason University, 4400 University Dr., MS3F5, Fairfax, VA 22030, USA; e-mail: gartenbergdaniel@gmail.com.

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INTRODUCTION

Pilots, automobile drivers, power plant workers, and supervisory control operators are required to allocate attention to multiple objects that must be monitored concurrently. Yet human attention is limited, resulting in the need to constantly shift attention between different objects in these dynamic tasks. These shifts in attention result in moment-to-moment fluctuations in situation awareness (SA). Take an example from a multirobot supervisory control task: If one vehicle needs help because it is on a collision course, the operator needs to attend to the vehicle in a timely manner. He or she must perceive the relevant objects, analyze the state of the objects, make a plan, and execute the plan by directing the vehicle to change course. During this time, the operator's attention is primarily on a single vehicle, and the operator may be unaware of or may forget other vehicles that need help. After such reductions in SA, a skilled operator must reassess the environment to recover SA; we call this process *situation awareness recovery* (SAR).

Background

Endsley (1995a) defined SA as consisting of three stages: the perception of elements in an environment, the integration of those elements into a comprehensible meaning, and the projection of that meaning into the future. When two aircraft are on a collision course, the operator must notice the location and state of the vehicles (perception stage of SA), aggregate that perception information to evaluate the situation (comprehension stage of SA), and project that situation onto future events (projection stage of SA). Loss of SA is often strongly correlated with degraded task performance (Durso et al., 1995; Endsley, 1995b), constituting the main cause of aircraft accidents in an analysis of over 200 incidents (Hartel, Smith, & Prince, 1991; Jones & Endsley, 1996); however, SA is distinct from

performance in that it precedes decision making and is not strongly correlated with performance in simple tasks (Endsley, 1995a).

Endsley's three-level model describes SA as a product, whereas other models emphasize the processes that underlie SA. For example, the perceptual cycle model (Smith & Hancock, 1995) highlights the cognitive processes involved in SA and the interaction between these processes and the environment (for a review, see Salmon, Stanton, Walker, & Green, 2006). Also, in Endsley's (1995b) seminal paper, several processing mechanisms were hypothesized to impact SA, including working memory, attention distribution, goal-directed processing, mental models, schemata, and automaticity. Indeed, Sohn and Doane (2004) found that working memory capacity was predictive of SA performance, especially for novices, and Gugerty and Tirre (2000) found a correlation between SA and working memory, perceptual motor ability, visual processing ability, and temporal processing ability. Although these studies show the cognitive abilities that are involved in SA, they do not demonstrate the mechanism by which these processes operate.

In order to extend Endsley's model by obtaining a fine-grained process understanding of how SA unfolds and fluctuates over the time course of a task, we introduce and investigate a new concept, SAR. SAR is defined as the process of restoring SA after SA has been reduced. A reduction in SA can be caused by a loss of attention, interruptions, multitasking, operator overload, and so on. Since interruptions can adversely affect SA, it is hypothesized that the operator will be more likely to engage in SAR after an interruption. If distinct perceptual and cognitive processes characterize SAR, then these processes can be identified and incorporated within a process account of SA.

There are subtle distinctions among the ways in which interruptions impact SA. As described by Boehm-Davis and Remington (2009), interruptions can differ based on the trigger of the interruption (endogenous versus exogenous); the disengagement from the primary task—whether the secondary task can be delayed or else needs immediate attention; and how the primary task is resumed—whether the primary task is dynamically changing during the interruption or else is static. McFarlane (2002) distinguished between interruptions that are immediate, whereby the operator does not control when he or she is interrupted, and those that are negotiated, whereby the operator can control when he or she is interrupted.

Trafton, Altmann, Brock, and Mintz (2003) presented a task-analytic framework for interruptions in which the ability to resume after an interruption is affected by the interruption lag and the type of interruption. The interruption lag is the time spent preparing for an interruption before it occurs. The type of interruption affects the ability to resume after an interruption because a secondary task that requires more cognitive demands limits the rehearsal of the primary task. Based on this framework, exogenous and immediate interruptions can be particularly damaging to SA because prospective goal encoding (i.e., "What was I about to do?"; Brondimonte, Einstein, & McDaniel, 1996) and retrospective memory rehearsal (i.e., "What was I doing?") are inhibited in these circumstances. Indeed, a longer interruption lag resulted in a shorter resumption lag (Trafton et al., 2003). Additionally, reduction in the cognitive demands of the secondary task mitigated the negative effects of an interruption (Monk, Boehm-Davis, & Trafton, 2004).

We argue here that after an interruption, SA is lost due to a specific set of processes. Memory traces decay because the operator is involved in another task, which results in the inability to detect/remember changes in the environment (Altmann & Gray, 2008; Hodgetts & Jones, 2006; Monk et al., 2004; Ratwani, McCurry, & Trafton, 2008; Trafton et al., 2003). If the memory trace was not well encoded, the interruption will have a more detrimental impact on SA. Although much is known about the impact of SA on task performance, the components of SA, and the cognitive processes involved in SA, it remains unclear how participants recover SA after it is degraded.

Memory for Goals (MFG) Theory of SAR

The MFG model (Altmann & Trafton, 2002) offers a promising framework for characterizing

the process of SAR. The MFG model is based on the theoretical construct of activation of memory elements—in particular, activation as construed in the ACT-R (Adaptive Control of Thought–Rational) cognitive architecture (Anderson et al., 2004). The MFG model was initially used to interpret how subgoals are suspended and resumed in a problem-solving task (Altmann & Trafton, 2002). MFG can also be applied to a task like supervisory control, wherein each vehicle represents a separate subgoal that must be perceived and retained in order for the situation to be comprehended and analyzed. MFG has since been used to explain the disruptive effects of a task interruption (Altmann & Trafton, 2007), and it has been used to explain sequence errors (Ratwani & Trafton, 2011; Trafton, Altmann, & Ratwani, 2011).

Two constraints of the MFG model make specific predictions regarding SAR: (a) the strengthening constraint and (b) the priming constraint (Altmann & Trafton, 2002). The strengthening constraint includes mechanisms by which memories for goals are established and reinforced. Specifically, the frequency and recency of goal retrievals strengthen the activation of the goal in memory. For example, working on a vehicle in a supervisory control simulation will strengthen the activation of the goal associated with that vehicle. The current most active goal is the one most likely to be retrieved and thus to direct behavior. Over time, the activation of a goal decays unless it is reactivated. Therefore, a goal retrieval request is more likely to return a recently and more frequently sampled goal. The need to reactivate goals suggests that during SAR, the operator will preferentially sample previously sampled objects rather than previously unsampled objects, thereby reactivating recent goal traces that have decayed.

The second constraint, the priming constraint of the MFG model, can be leveraged to make predictions about SAR. The priming constraint posits that contextual retrieval cues, such as a vehicle's visual representation, can provide associative activation or priming that can boost the activation of a goal. In the MFG model, as an operator works on a vehicle, that event is encoded as an episodic code that can decay during an interruption. This decay causes reduced SA and a need for the operator to make the additional step of examining the environment to refresh the activation of decaying episodic codes. A result of this extra recovery step is that it will take more time to perform a task having a task suspension than a task with no suspension (Trafton et al., 2003). This increase in time after an interruption is known as the resumption lag. In other words, after an interruption, the operator is less familiar with the environment (i.e., has reduced SA) because the episodic codes for the situation and environment have decayed and so attends to cues, which results in taking a longer amount of time to recover his or her awareness than without interruption.

Combining activation, decay, and priming, MFG thus yields the following predictions of where the operator's attention will be drawn in order to improve SA. When the activation of memory elements is low, such as when decay has occurred after an interruption, the operator must engage in SAR in order to reinstate the previous context and recover SA. In a simple model, one might imagine a system whereby the operator nondiscriminately samples across goals based on bottom-up cues, such as saliency. Yet in the MFG theory, priming acts as the mechanism by which previous goals are reinstated and SA is restored. In other words, after a period of low SA, when there is partial, though decayed, memory of the situation, MFG predicts that top-down location-based memory cues prime the goal state. These cues are dependent on the goal state. Thus if the objective of the task is to prevent vehicles from intersecting with hazards, the effective cues are the objects (vehicle, hazard, target) involved in the intersect scenario. MFG thus predicts that following an interruption, operators will engage in SAR by attending to previously attended objects, which prime and therefore raise the activation of previous goals and plans. In effect, these old objects are acting as contextual cues that promote the recovery of situation awareness.

Although this scenario is consistent with Endsley's model for goal-directed processing (Endsley, 1995b), Endsley's model describes how goals impact information processing at a higher level than MFG. Because MFG describes how goals decay and are activated over a fine-grained time course, it can make explicit predictions

about how contextual cues can be strategically used by the operator to improve SA.

The integrated framework for maintaining and recovering SA proposed by St. John and Smallman (2008) involves concepts similar to the MFG model to make predictions about where attention will be allocated. St. John and Smallman organized SA into four stages: (a) change detection before an interruption, (b) preparing for an interruption, (c) reorientation after an interruption, and (d) change detection after an interruption. Similar to the SAR prediction from the MFG model that participants look at contextual cues when recovering SA, the integrated framework includes an additional reorientation step following an interruption. Yet when there is no interruption, the goal state is less degraded, and there is less need to add the additional step of attending to a context cue (i.e., reorienting). Whereas the integrated framework is relatively descriptive, the MFG characterization of SAR specifies the processes underlying the reorientation stage.

The MFG model also predicts what operators will do when there is no disruption of SA, as when there is no interruption. In these cases, attention is free to be allocated to detecting changes or previously unexplored objects in the environment. Therefore, another prediction is that attention will likely be directed to novel stimuli when SA is relatively high and SAR is not necessary.

Typically, SA is measured using query methods. The situation awareness global assessment technique (SAGAT) involves freezing the computer screen and probing the operator with questions related to the operator's current SA (Endsley, 2000). Similarly, the situation present assessment method (SPAM) involves probes but administers the probe online, during the task, and without freezing the screen (Durso et al., 1995). These tools can measure the overall state of SA or the level of SA at a specific moment in time. However, these tools are indirect verbal measures of the perceptual processes that occur during the performance of a dynamic task.

In order to more directly measure the process of SAR, we measured operators' eye movements, together with a modified SAGAT, to test our predictions regarding visual attention and memory during SAR versus during situations when SA is relatively high and SAR is less necessary. According to the MFG model, an interruption will induce behaviors indicative of SAR, such as an increased resumption lag and more fixations on objects that were previously looked at. The reason for this result is that the interruption causes the episodic codes for the situation to decay, resulting in the need to take more time to examine the situation and a greater need to reactivate the goal state through the use of associative priming. In contrast, when SA is higher, such as during continuous task performance, without an interruption, it is hypothesized that there will be a shorter resumption lag, fewer refixations, and more novel object fixation. There will be more novel fixations because attention is free to detect new events in the environment when there is no interruption. This experiment identifies the perceptual and cognitive processes that characterize SAR by inducing SAR through immediate interruptions and negotiated interruptions and compares instances of SAR with situations in which SA is relatively high.

EXPERIMENT 1

To investigate SAR, we presented participants with short videos of a supervisory control task that was performed by another operator. We then manipulated whether or not there was an immediate interruption during the playing of the video. There was no alert before the interruption, so preparation was presumably minimal. During the interruption, the primary task was hidden and participants performed arithmetic problems. Task difficulty was also manipulated on the primary task to ensure that the hypothesized behavior is found in a wide range of situations. After each trial, participants answered questions that were adapted from the SAGAT and designed to assess the perception and comprehension components of SA. Asking questions of the participant after each trial provided a measure of SA and kept the participant engaged.

Method

Participants. Thirty George Mason University undergraduate students participated for extra credit. All participation was voluntary. One participant was eliminated due to instrument

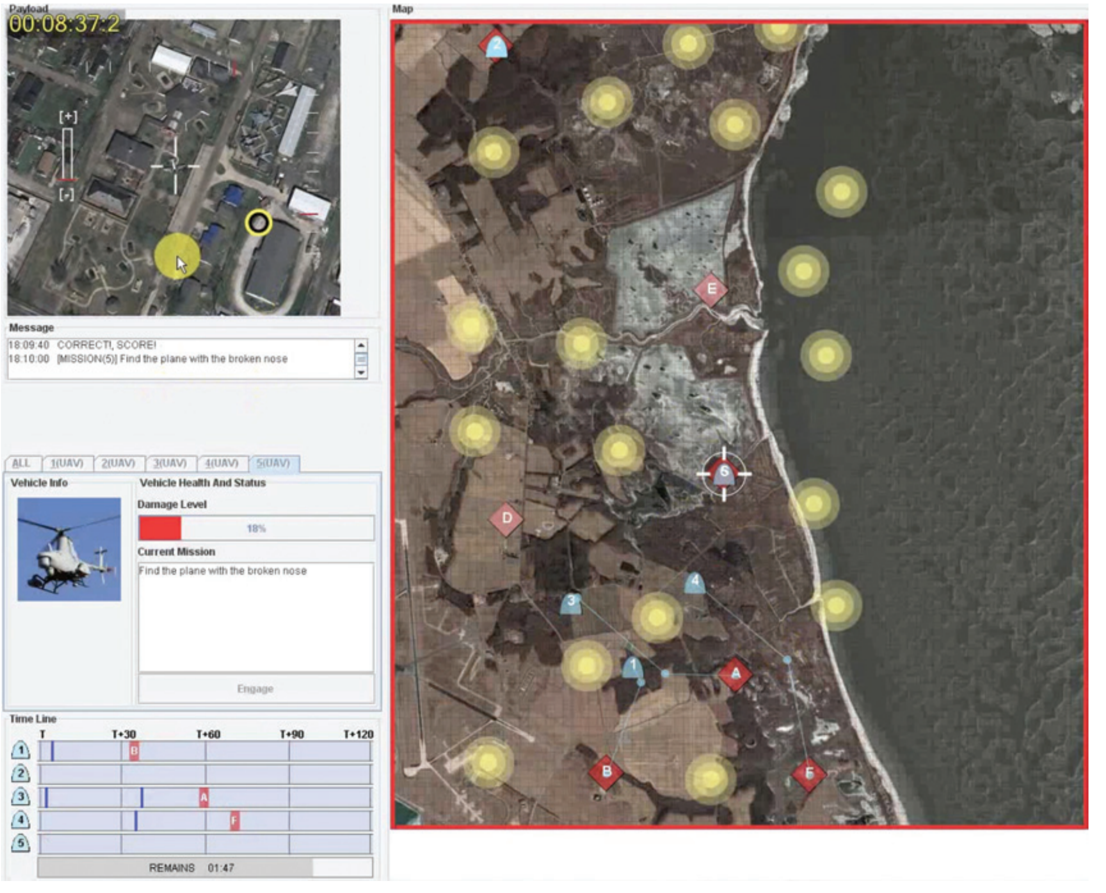

Figure 1. Research Environment for Supervisory Control of Heterogeneous Unmanned Vehicles supervisory control task.

malfunction. Two participants were eliminated because they performed at or below chance on the SAGAT questions. In total, 27 participants' data were analyzed.

Data from 15 females and 12 males were analyzed. The average age of participants was 21.7 years old with a standard deviation of 3.6 years. Participants were asked to rate how often they played video games on a scale of 1 (*never*), 2 (*sometimes*), or 3 (*a lot*). The average amount of video game play was 1.9 with a standard deviation of 0.7. All participants had normal or corrected-to-normal vision.

Materials. The Research Environment for Supervisory Control of Heterogeneous Unmanned Vehicles (RESCHU; Boussemart & Cummings, 2008) was the supervisory control simulation used in this study. In our version of the RESCHU task, homogenous unmanned aerial vehicles (UAVs) moved on a computer screen in an environment that was dynamically changing. There were three main sections in the simulation: the map window on the right, the payload window on the upper left, and a status window on the lower left (see Figure 1). The map area displayed UAVs (blue half ovals); targets (red diamonds), toward which UAVs were directed by the system; and hazards (yellow circles), which should be avoided. Vehicles were labeled with numbers and targets were labeled with letters. The payload window (top left) displayed a visual search photograph image in which the participant was directed to locate a target object based on written instructions as part of a payload delivery operation (described later). The status window (bottom left) depicted a timeline of each UAV's past and upcoming milestones, including the waypoints and the target of each UAV.

The simulation included five UAVs that moved at a fixed speed throughout the duration of the task. There were 18 hazard areas, one of which changed its position randomly every 4 s, with the constraint that the hazards could not appear within 3° of visual angle (about 50 pixels) of any UAV. If the UAV passed through a hazard, it incurred damage. Damage was indicated as a red bar in the status window. The location of targets and hazards on the simulation map was randomized with the constraint that targets and hazards were no closer than 3° of visual angle from each other. This design ensured that targets and hazards could not co-occur in the same position. There were always seven targets present on the map.

The participant viewed a screen-capture video of a session of an operator's interaction with the RESCHU simulation. An operator directed UAVs to target areas while avoiding hazard areas. To avoid a hazard area, the operator could assign the UAV to a different target, or the operator could add waypoints to the UAV's trajectory, which effectively allowed the operator to pilot the UAV around hazard areas. The operator could also move or delete waypoints. At the start of the simulation, the UAVs were randomly assigned to targets toward which they moved along automatically generated linear paths. Once the UAV reached the target destination, the target flashed red until it was engaged. A target was engaged when the operator right-clicked on the vehicle and selected the appropriate pop-up menu item. Engaging the vehicle triggered the payload task, whereby the operator performed a visual search task to identify an object, such as a ship or a car, in the payload window.

During the payload, the vehicles in the map panel continued to move toward their respective targets, and operator input to the map panel was disallowed. After identifying the object in the payload panel, the UAV's mission was completed. The UAV was then randomly assigned to a new target that did not already have a UAV assigned to it.

Each simulation session had unique characteristics with randomly generated trajectories, locations, and objectives, similar to a real-world environment. RESCHU requires the operator to manage multiple events that occur in parallel: More than one UAV could be waiting at a target for engagement, multiple UAVs could be on a path to a hazardous area, and it was left to the operator's discretion to act on any one of the five vehicles.

Videos of RESCHU. In this experiment, the participant was not the operator but instead the observer of a recording of an actual human operator's interactive session. To enable a high degree of experimental control, multiple videos were created of the user interface while the operator performed the RESCHU task. Each video clip trial was 8 s long and did not include a payload. There were two versions of each 8-s video clip. One version included the full 8 s without interruption, whereas in the other version, the 8-s video was cut in half to create two videos that were each 4 s long and had an interruption between them.

The video clips differed based on the number of vehicles that needed attention. A vehicle needed attention either when it was on path to intersect a hazard or when the vehicle was ready to be engaged. There were 10 unique videos in the practice task and 72 unique videos in the experimental task. Of the 72 videos, there was an equal number of trials in which one, two, or three vehicles needed attention, for a total of 24 trials for each condition. Half of the video clips were randomly assigned to the interruption condition, wherein an interruption was added between the first half and the second half of the video. In the continuous-trials condition, the 8-s video clip was displayed without interruption. In the interruption condition, the participant was required to perform math problems during the break. These math problems consisted of three simple questions, whereby the participant was required to add three single-digit numbers together. The mean duration of the math problems was 6,935 ms, with a standard deviation of 2,395 ms.

The video clips were displayed using E-Prime experiment software, which collected user responses to questions that were presented after each trial. After each trial, two types of questions about the simulation were asked of the participant. The questions were modeled on the SAGAT (Endsley, 2000), such that the perception and comprehension components of SA

Perception

1. Is vehicle X idle?
2. Is vehicle X on path to hazard?

Comprehension

1. How many vehicles are on path to hazard?
2. How many vehicles are idle?

Figure 2. Situation awareness global assessment technique questions (*X* refers to a vehicle's numerical label).

could be evaluated. The questions also kept the participant engaged in the task. After each trial, one perception question and one comprehension question were randomly presented to the participant. The perception questions involved identifying the state of a single vehicle, whereas the comprehension questions required the participant to integrate information about all the vehicles in order to make a judgment about the global situation state (see Figure 2). This method conformed to Endsley's (1995b) definition of the comprehension stage of SA as the "synthesis of disjointed elements."

Design and procedure. The experiment had a within-subjects design with two independent variables: (a) interruption versus no interruption and (b) number of vehicles needing attention (one, two, three vehicles), resulting in six different types of video clips, which were presented in random order. Each participant viewed 12 of each of the six types of video clips.

All participants began the experiment by completing an interactive tutorial that explained all aspects of the simulation. Participants learned about the objective of the simulation: to prevent as much damage as possible and engage as many vehicles as possible. Additionally, participants learned how to control the UAVs (changing targets, assigning/deleting/moving waypoints) and how to engage a target (by right-clicking on the target and selecting the engage menu item in the pop-up menu). Participants were also warned of the dangers of hazards and were instructed on how to avoid hazards. The tutorial lasted approximately 10 min.

After the tutorial, participants were instructed to practice interacting with the RESCHU task until they understood the task and could complete each subactivity. Then participants were reminded that the goal of the task was to prevent as much damage as possible and engage as many vehicles as possible. Following this instruction, participants were exposed to 5 min practice performing the RESCHU task. Participants were again instructed to maximize their score by engaging as many targets as possible and preventing as much damage as possible. When the simulation ended, participants received feedback on how many vehicles they engaged and the total amount of vehicle damage.

After practicing the RESCHU task, participants were asked if they had any questions. They were then given instructions on the videos they were about to view of the RESCHU task. Participants were told that they would be presented with short video clips. After these video clips were presented, the participant was asked to answer questions about the clips. As is conventional with the SAGAT, participants were given examples of all of the questions that they would be expected to answer about the video clips. Participants were also told that some of the videos would be interrupted by short math problems that they would have to complete as quickly and accurately as possible. In order to ensure understanding of the task, participants were given 10 practice trials. After completing the practice, participants were again asked if they had any questions.

Participants were then seated approximately 66 cm from the computer monitor and were calibrated on an eye tracker. Participants then began the task. The 72 videos were presented in random order to participants. The order of each type of question (i.e., perception and comprehension) was also randomized. The interruption occurred randomly on half of the trials. After the task ended, participants were debriefed.

Measures. Keystroke data were collected for each participant in order to evaluate their responses to the SAGAT questions. Eye-tracking data were collected using an SMI eye tracker operating at 250 Hz. A fixation was defined using the saccade-based method, whereby fixations occurred between the saccades. A saccade was defined as an eye movement velocity faster than 30° per second.

The pattern of eye movements in the second half of the video clips was analyzed in order to make a direct comparison between instances of

SAR (i.e., when there was an interruption) and instances when SA was likely to be higher (i.e., when there was uninterrupted task performance). That is, the interval of time directly after the math problems was compared with the corresponding interval of time when there was continuous presentation of the video.

Fixations were categorized based on their object of focus. There were a total of five UAVs on the screen, each having a different target and possibly hazards associated with it. A vehicle, the vehicle's relevant hazard(s), and the vehicle's relevant target were classified as a "separate vehicle cluster." Since there were a total of five vehicles, there were five respective separate vehicle clusters. A fixation on an object was categorized by the object's vehicle cluster. Fixations on nonrelevant hazards and targets were removed from the analysis.

Separate vehicle cluster fixations were further characterized, using the second half of the video clip, as either refixations or novel fixations. A refixation occurred when participants looked at the same vehicle cluster in both halves of the video clip, whereas a novel fixation occurred when participants looked at the vehicle cluster in only the last half of the video clip. This categorization was then used as an independent variable in order to test the hypothesis regarding the types of fixations that occur during SAR. For example, during the first half of the video, the participant could look at Vehicle 1, Vehicle 2, and Vehicle 3 (or its respective target or hazard) and then, after the halfway point, fixate again on an object in Vehicle 1's cluster. That fixation would be classified as a refixation, but if the participant then fixated on Vehicle 5, the fixation would be classified as a novel fixation.

Results

Performance on the modified SAGAT. In order to determine the impact of interruptions on SA, accuracy on the modified SAGAT was compared in the interruption and no-interruption conditions. In order to determine the impact of the number of vehicles that needed attention on SA, accuracy on the modified SAGAT was compared when one, two, or three vehicles needed attention.

Accuracy was determined for the perception questions and the comprehension questions by taking the average percentage correct of the two questions of those respective types. For the perception question, there was no significant difference in accuracy between the interruption condition (M = 86.72%, SD = 8.58%) and continuous task condition (M = 86.72%, SD = 10.23%), $F(1, 26) = 0.02$, $p = .89$, $\eta^2 = .00$; however, as the number of vehicles that needed attention increased, accuracy declined, $F(2, 52) = 10.57$, $p < .05$, $\eta^2 = .29$. Planned contrasts showed that accuracy on the perception question was worse when three vehicles needed attention than when one vehicle needed attention ($p < .05$) or when two vehicles needed attention ($p < .05$). There was no interaction between interruption and number of vehicles that needed attention, $F(2, 52) = 0.53$, $p = .59$, $\eta^2 = .02$. This finding suggested that the number of vehicles that needed attention was a determinant of the difficulty of the perception stage of SA but that interruption did not significantly impact the perception stage of SA (see Figure 3).

For the comprehension questions, there was worse accuracy in the interruption condition (M = 74.79%, SD = 10.59%) than in the continuous task condition (M = 84.05%, SD = 9.58%), $F(1, 26) = 32.41$, $p < .05$, $\eta^2 = .55$. Additionally, as the number of vehicles that needed attention increased, accuracy declined, $F(2, 52) = 15.70$, $p < .05$, $\eta^2 = .38$. Planned contrasts showed that accuracy on the comprehension question was better when one vehicle needed attention than when three vehicles needed attention ($p < .05$), and accuracy on the comprehension question was better when two vehicles needed attention than when three vehicles needed attention ($p < .05$). There was no interaction between interruption and number of vehicles that needed attention, $F(2, 52) = 1.01$, $p = .37$, $\eta^2 = .04$ (see Figure 3).

Thus, interruptions did not seem to significantly impact the perceptual stage of SA but had a detrimental impact on the comprehension stage of SA. However, the number of vehicles needing attention had a detrimental impact on both stages of SA.

Number of fixations. Whereas the questionnaire assessed SA, fixations provided insight into participants' strategies for compensating for reduced SA. One manner to compensate for reduced SA is to increase scanning in an attempt to restore SA. In order to determine if there were differences in the number of fixations between

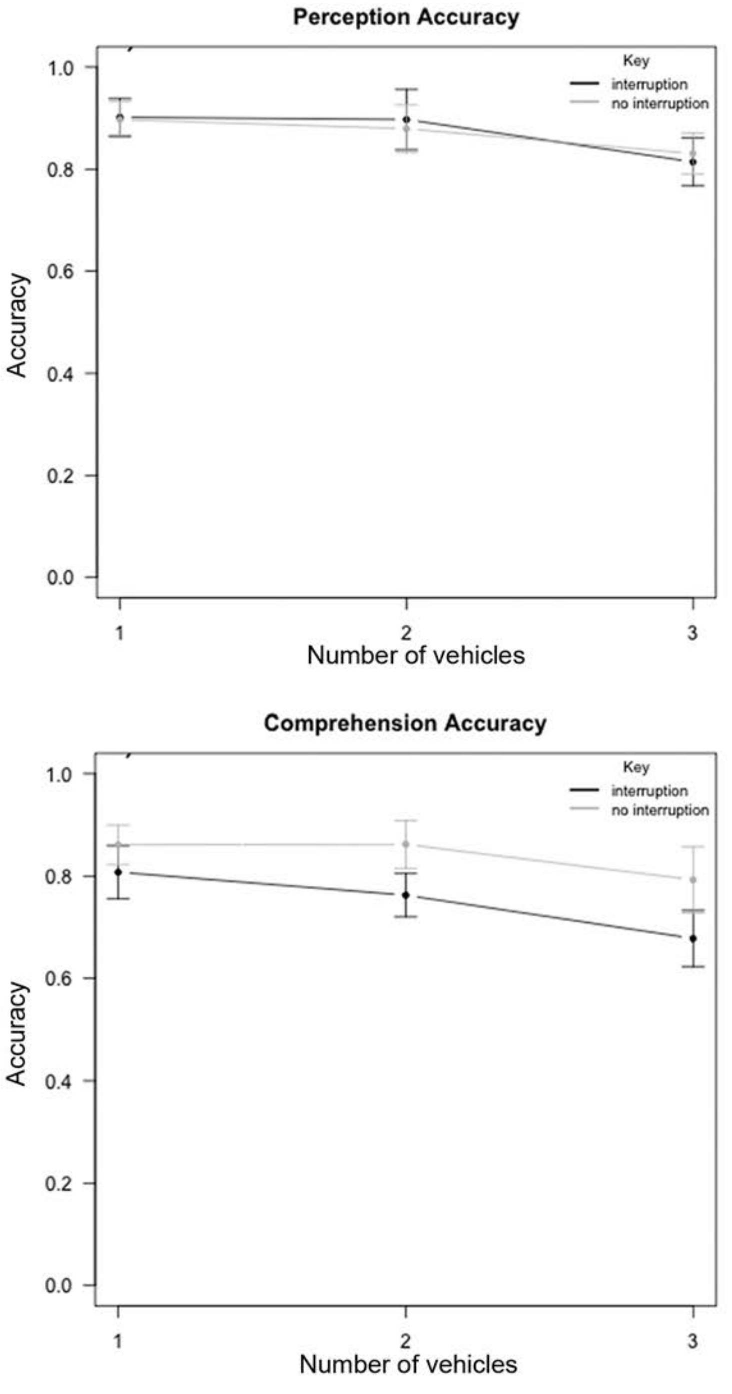

Figure 3. Accuracy on situation awareness global assessment technique questions as a function of the number of vehicles needing attention and of interruption versus no-interruption condition (i.e., the continuous task condition). Error bars are 95% confidence intervals.

the interruption condition and the continuous task condition, we examined the number of separate vehicle cluster fixations that occurred in the second 4 s of each trial. The dependent

variable was the number of separate vehicle cluster fixations; thus the number of separate vehicle cluster fixations was between 0 and 5, since there were five vehicles in the simulation. There was a marginal effect of interruption on the number of separate vehicle cluster fixations in the second half of the videos, with more vehicle cluster fixations in the interruption condition (M = 3.15, SD = 0.71) than in the continuous task condition (M = 3.01, SD = 0.71), $t(26)$ = 3.68, p = .07, d = .20.

Fixation duration. One unexpected difference between the interruption condition and the continuous task condition was that fixation duration for all relevant objects was different between conditions in the second half of the video trial. Fixation duration in the second half of each trial was shorter in the interruption condition (M = 196 ms, SD = 43 ms) than in the continuous task condition (M = 216 ms, SD = 54 ms), $t(26)$ = 3.72, $p < .05$, d = .41. This finding may explain why there was a marginal effect of number of fixations, with more fixations in the interruption condition. During SAR, participants may have quickly scanned the screen in order to recover awareness of the key elements involved in the situation. Perhaps participants made shorter fixations in the interruption condition in an effort to examine more objects (i.e., they made more fixations).

Novel fixations versus refixations. Recall that MFG predicts that there will be more refixations after an interruption for the purpose of reactivating decayed memory codes through associative priming. Additionally, it was predicted that there would be more refixations in the interruption condition because refixations can prime the activation of decaying memory traces. We used a within-groups ANCOVA to examine the relationship between fixation type (novel, refixations) and interruption (interruption, continuous task) on the dependent variable of number of separate vehicle cluster fixations in the second half of the 8-s trials. Furthermore, we included the number of vehicles that needed attention as a covariate. After controlling for the number of vehicles that needed attention, there was no difference in the number of separate vehicle cluster fixations in the interruption condition (M = 1.56, SD = 0.98) compared to the continuous task condition (M = 1.50, SD = 0.83), $F(1, 26)$ = 3.59, p = .12, η^2 = .29. However, there was a main effect of fixation type after controlling for the number of vehicles that needed attention, $F(1, 26)$ = 77.22, $p < .05$, η^2 = .75, with more separate vehicle cluster fixations on vehicles that were previously looked at, that is, refixations (M = 2.21, SD = 0.78), than on vehicles that had not previously been looked at, that is, novel fixations (M = 0.85, SD = 0.29).

Consistent with MFG, there was a two-way interaction between fixation type and interruption after controlling for the number of vehicles that needed attention, $F(1, 26)$ = 18.43, $p < .05$, η^2 = .42. In planned contrasts, all groups were significantly different from all other groups ($p < .05$), with the exception of a marginal effect for the comparison between novel fixations in the interruption condition versus the continuous task condition (p = .07). As Figure 4 suggests, SAR was distinguished by more refixation in the interruption condition than in the continuous task condition and marginally fewer novel fixations in the interruption condition than in the continuous task condition.

Discussion

We sought to decrease SA in order to understand SAR by manipulating whether or not participants were exposed to immediate interruptions. We predicted that interruptions would undermine the perception and comprehension components of SA. A decreased level of SA requires participants to engage in SAR in order to refresh their memory. The MFG model predicts that during SAR, participants will refixate on objects that were previously looked at in order to prime their memory of the environment. However, when there is no interruption, SA is relatively higher, enabling the participant to allocate attention to detect novel elements in the environment.

Since there were separate measures of SA and SAR, reduced SA could be related to specific SAR behaviors. Interestingly, perception SA did not differ between the interruption-versus-continuous conditions, but comprehension SA was worse for the interruption condition than for the continuous condition. Comprehension is a later stage of SA than perception because it is necessary to perceive

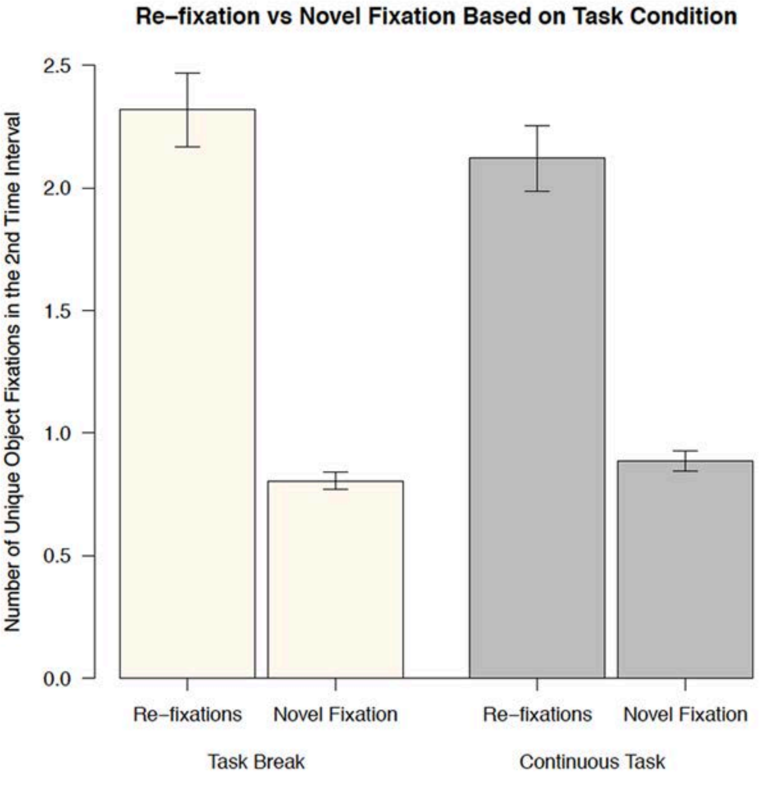

Figure 4. Type of fixation based on task condition. Error bars are 95% confidence intervals.

elements in an environment before their meaning can be comprehended. For example, it is impossible to determine that three vehicles are on path to intersect with a hazard before first looking at each vehicle, analyzing its trajectory, and identifying that they will intersect with a hazardous area. Since comprehension SA depends on first acquiring perception SA, comprehension SA takes longer to be reacquired, and therefore it might be more vulnerable to disruption than perception SA. The finding that participants performed worse on SA comprehension after an interruption explains why they would need to do more SAR when there was an interruption than when there was no interruption.

The eye-tracking data supported our MFG-based hypothesis regarding where attention is allocated during SAR. After an interruption, during SAR, participants fixated more on objects that were previously looked at and fixated on relevant novel objects marginally less than during continuous task performance. MFG supports this nuanced finding because MFG predicts that after a break, the goal representation needs to be reinstated through either internal (memory/imagination) or external (fixation) cues. In support of this, participants fixated on objects that were previously gazed on after an interruption in order to reinstate their previous memory representation. We interpret this finding as indicating that participants use contextual cues to increase activation of the memory state during SA recovery. In contrast, during continuous task execution, when there is no interruption, participants had less need for SAR because they preserved their SA. Thus, when there was no interruption, participants spent marginally more time seeking out novel aspects of the environment.

In addition to characterizing the type of fixations involved in SAR, our data revealed, surprisingly, that fixations were of shorter duration when SA was disrupted by an interruption than when SA was not disrupted. Faster fixation durations and a marginal increase in the number

of fixations in the second half of the interruption condition suggest that a characteristic of SAR is to cause someone to scan the environment more thoroughly by looking at objects for a shorter duration of time.

In sum, we identified a new concept, SAR, and found perceptual and cognitive processes that characterize SAR, including more refixations and shorter fixation durations. However, in Experiment 1, we could not test predictions about the hypothesized resumption lag after an interruption because trial duration was fixed and there was no timed response. Additionally, there were task constraints in Experiment 1 that may explain the findings, such as the fact that participants passively watched videos and answered questions related to those videos, instead of actively engaging in the RESCHU task. SA may be lower when passively viewing a task, and passive viewing may impact behavior (Endsley & Rodgers, 1998). Additionally, SAR may differ under less constrained scenarios; for instance, flexible trial durations permit the participant to more fully scan the environment; and enabling the participant to choose when he or she is interrupted, by administering a negotiated interruption instead of an immediate interruption, may mitigate the need for SAR. The task constraints and the environment can be driving forces that affect operator SA (Kirlik & Strauss, 2006; Smith & Hancock, 1995), and these constraints may explain the findings regarding SAR. To address these issues, and to determine if our findings generalize to a more dynamic and actively engaged task, we conducted another experiment to determine if the perceptual and cognitive processes that characterized SAR in this experiment are replicated when participants perform the RESCHU simulation.

EXPERIMENT 2

Experiment 1 offered support for the hypothesized cognitive and perceptual processes that underlie SAR. To determine whether the findings of Experiment 1 occur when participants are actively engaged in a dynamic task, and when the participant can control the timing of an interruption, participants performed the RESCHU task under either a negotiated interruption or continuous task condition. Participants had some control over exactly when their secondary task occurred because engaging the vehicle caused the interruption to begin. The interruption was a visual search task that involved delivering a payload (upper left corner of Figure 1). This payload delivery task was the negotiated interruption to the main task in the map panel. In the continuous task condition, no interrupting payload delivery task was required after engaging a vehicle. Another difference between Experiment 2 and Experiment 1 was that during the payload, the main task was not suspended. We hypothesized that an interruption will impair SA and, as a result, induce the process of SAR. Also, since trial durations were not fixed in Experiment 2, it was possible to assess task resumption time. We predicted that a characteristic of SAR would be increased task resumption time.

Method

Participants. Eighty-one George Mason University undergraduate students participated for extra credit. All participation was voluntary and participants had no prior experience with the task. Eye data for 3 participants were eliminated because it was not accurately captured. In total, 78 participants were analyzed: 38 in the interruption condition and 40 in the continuous task condition.

Data from 58 females and 20 males were analyzed. The average age of participants was 20.4 years old with a standard deviation of 3.0 years. Participants were asked to rate how often they played video games on a scale of 1 (*never*), 2 (*sometimes*), or 3 (*a lot*). The average amount of video game play was 1.8 with a standard deviation of 0.7. All participants had normal or corrected-to-normal vision.

Materials. Materials were identical to the RESCHU task described in Experiment 1, with the exception that the premade videos of the RESCHU task were not used. Instead, participants interacted with the simulation.

Design and procedure. The experiment had a between-groups design. One group was assigned to the continuous task condition, and the other group was assigned to the interruption condition. The interruption consisted of a visual search payload task following vehicle engagement. The

dependent variables were patterns of eye fixations directly after the participant completed a vehicle engagement (continuous task condition) or else after they completed a vehicle engagement followed by a visual search payload task (interruption condition), which constituted an interruption from the primary task. The average duration of the visual search payload task interruption was 6,307 ms, with a standard deviation of 1,504 ms. By converting the time of the interruption to distance traveled, we found that on average, the vehicles moved 33 pixels during the visual search payload task, with a standard deviation of 8 pixels. Once engaged in the visual search payload task, the participant was unable to complete any other actions in the simulation until the visual search task was completed.

The procedure was identical to Experiment 1 except that after the practice, participants used the RESCHU simulation. Participants were calibrated on the eye tracker, were seated approximately 66 cm from the screen, were told to try to avoid damage as much as possible and to engage as many vehicles as possible, and then were administered a 10-min session on RESCHU. This session was followed by a brief break, after which a second 10-min RESCHU session was administered in the same manner as the first. Participants were run in the same condition for both 10-min sessions, and both sessions were combined in the analysis.

Measures. The eye movement measures were identical to Experiment 1, except that the interval of time that was analyzed was different. We parsed the session into discrete events in a similar manner as Crandall, Goodrich, Olsen, and Nelson (2005) and Altmann and Trafton (2004), by dividing the task into intervals in which either (a) participants *monitor* the screen and decide what to do next or (b) participants *perform actions*. The monitoring interval of particular interest was the interval that began after an engagement completion. This interval immediately followed the interruption, consisting of a visual search task in the task-break condition or else immediately followed target engagement in the continuous condition. Examining the monitoring interval after the mission completion and before the beginning of the next action, whether an engagement or a hazard evasion action, enabled us to compare functionally equivalent intervals in the two conditions. The duration of this monitoring interval differed depending on how long it took the participant to initiate the next action.

Results

All analyses were conducted on the monitoring interval of time after the mission completion and before the next action. On average, participants completed 54.3 missions across the two 10-min sessions, resulting in an average of 54.3 monitoring intervals that were analyzed per participant.

Resumption lag. Recall that MFG predicts that after an interruption, participants will take longer to initiate their next action, which is known as the resumption lag. According to MFG, participants take longer to respond after an interruption because it causes episodic codes for the situation to decay. In response to this decay, the participant must refixate on objects in order to reactivate the goal state through associative priming. Consistent with MFG, participants in the interruption condition experienced a longer resumption lag; they took longer to resume (M = 5,033 ms, SD = 1,145 ms) than did participants in the continuous task condition (M = 4,124 ms, SD = 1,122 ms), $t(76) = 3.54$, $p < .05$, $d = .80$. This finding is consistent with other research that has shown increased resumption lag after an interruption (Hodgetts & Jones, 2006; Monk et al., 2004; Trafton et al., 2003).

Fixation duration. Consistent with the findings from Experiment 1, fixation durations in the interruption condition were shorter (M = 314 ms, SD = 69 ms) than in the continuous task condition (M = 404 ms, SD = 82 ms), $t(76) = 5.24$, $p < .05$, $d = 1.19$. This finding suggested again that during SAR, participants quickly scan objects in the environment in order to sample objects in the environment and reactivate their awareness for those objects.

Novel fixations versus refixations. In Experiment 1, there was an interaction between fixation type and task condition, with more refixations in the interruption condition and marginally more novel fixations in the continuous task condition. To explore whether this effect occurs when actively engaged in a dynamic task, we ran a mixed ANOVA to examine the relationship between novel fixation or refixation

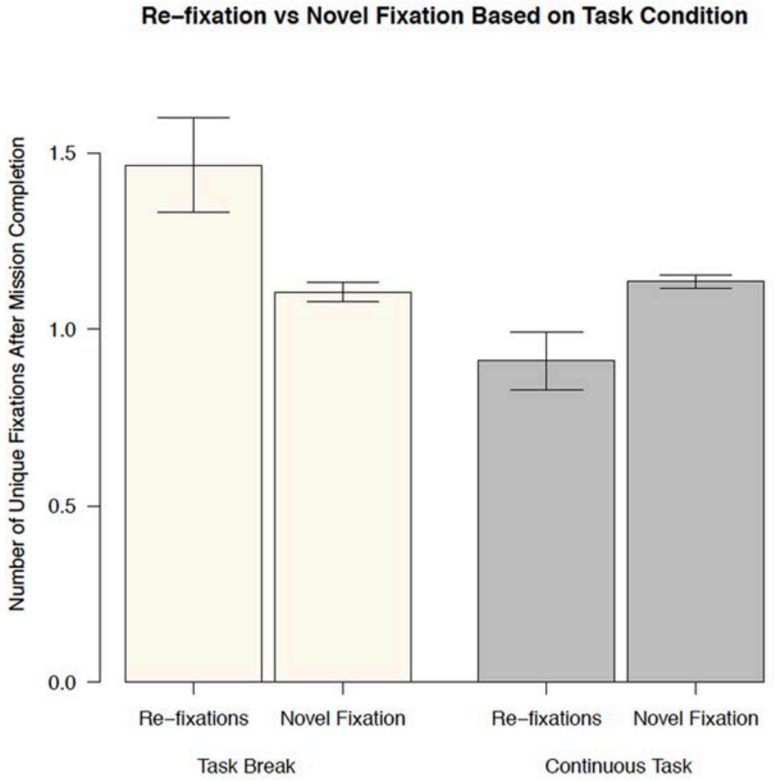

Figure 5. Type of fixation based on task condition. Error bars are 95% confidence intervals.

and continuous task or interruption. Task condition (interruption or continuous task) was the between-groups factor and fixation type (refixation or novel fixation) was the within-groups factor. The dependent measure was the number of separate fixation clusters that occurred in the monitoring interval after the mission completion and before the next action.

Consistent with MFG, there was a main effect of task condition, with more separate vehicle cluster fixations in the interruption condition ($M = 1.29$, $SD = 0.36$) than in the continuous task condition ($M = 1.02$, $SD = 0.21$), $F(1, 76) = 40.55$, $p < .05$, $\eta^2 = .40$. This finding, together with the finding of shorter fixation duration, suggests that the interruption resulted in increased scanning due to quicker fixations and more fixations, presumably in the service of SAR. There was a marginal main effect of fixation type with more refixations ($M = 1.19$, $SD = 0.49$) than novel fixations ($M = 1.12$, $SD = 0.09$), $F(1, 76) = 3.27$, $p = .07$, $\eta^2 = .04$. Also consistent with the MFG model of SAR, there was an interaction between task condition and fixation type, $F(1, 76) = 49.72$, $p < .05$, $\eta^2 = .40$. All groups were significantly different from all other groups ($p < .05$ using planned contrasts), with the exception of the difference between the number of novel separate fixations in the continuous task condition versus the interruption condition ($p = .17$). As Figure 5 suggests, in the interruption condition, there were more refixations than novel fixations, but in the continuous task condition, there were marginally more novel fixations than refixations.

Discussion

In this experiment, SAR was identified by comparing the cognitive and perceptual processes that occurred in an interruption condition with those that occurred in a continuous task condition, without an interruption. After the interruption, participants took longer to initiate the next action, were more likely to refixate on

TABLE 1: A Summary of the Characteristics of Situation Awareness Recovery (SAR) and the Memory-for-Goals (MFG) Explanation

Characteristics of SAR	MFG Explanation
More refixations and fewer novel fixations	Refixations act as contextual cues that prime memory for the situation and thereby boost situation awareness (SA).
Longer resumption lag	Participants must spend time recovering SA before they can decide what action to take next.
Shorter fixations and more fixations	In an effort to reactivate degraded memory traces, participants sample more of the environment.

previously viewed objects, made shorter fixations, and made more fixations.

MFG was supported by the pattern of fixations. In the interruption condition, SAR activities included fixating on previously viewed environmental cues, presumably in the service of reactivating memory traces, more than on novel objects. Additionally, in the continuous task condition, which we assume required less SAR, participants had more fixations on novel objects than on previously viewed objects. Experiment 2 also replicated the finding in Experiment 1 that participants made shorter-duration fixations when performing SAR and, in contrast to Experiment 1, made significantly, rather than marginally, more fixations during SAR, suggesting an effort to recover SA by more thoroughly scanning the environment.

A prediction of MFG is that participants take longer to respond after an interruption due to the need to reactivate decayed episodic memory chunks. In support of this hypothesis, participants took longer to take their next action after an interruption than under continuous task performance. This increased resumption lag may also explain why there were more fixations after an interruption than after continuous task performance. Therefore, in Experiment 2, we replicated our findings from Experiment 1 and identified additional perceptual processes that characterize SAR in a more realistic task, which included increased resumption lag and more fixations (see Table 1).

GENERAL DISCUSSION

Two methodologies were used to identify the perceptual and cognitive processes that characterize SAR. In Experiment 1, participants viewed short video clips of the RESCHU supervisory control simulation and either experienced an interruption halfway through the video or experienced a continuous clip without an interruption. In Experiment 2, participants actively engaged in the RESCHU simulation and were assigned to either an interruption scenario in which engaging the vehicle was followed by a visual search interruption or a scenario in which no interruption occurred. In both experiments, the time interval after the interruption was the focus of the analysis.

In Experiment 1, perceptual and comprehension SA were assessed by a SAGAT-based questionnaire. Although there was no difference in perception SA between the interruption and continuous conditions, comprehension SA was significantly impaired by the interruption. This finding suggested that later stages of SA are more susceptible to disruption and that interruptions induce the need for SA to be recovered. This result meant that we could test our predictions regarding SAR by comparing the behaviors in the second halves of the video clips for the two conditions.

Our predictions concerning SAR were based on the MFG theory. Although Endsley's (1995b) model describes at a high level the role of goal-directed processing in guiding attention, it does not make predictions about how participants activate goals in specific situations. Using MFG allowed additional, fine-grained process predictions to be made in a dynamic task. In the MFG model, the loss of SA is due to decayed memory traces for previous goals, which can occur even after very short interruptions (Altmann, Trafton, & Hambrick, in press), and thus SA recovery

following even these brief interruptions involves the reactivation of the memory traces. Memory traces are reactivated through the search for memory cues, for example, objects that are related to decayed goals. Eye movements provided evidence of this sort of SAR search, including short-duration fixations and refixations on objects that had previously been examined.

Experiment 2 replicated the findings from Experiment 1 in the context of active user interaction with the simulation environment and revealed additional behaviors that characterize SAR. These findings included an increased number of fixations, a longer resumption lag, and fewer fixations on novel objects. These findings suggested that participants sample the environment more during SAR in an effort to increase activation for decayed memories and goals.

Taken together, these experiments identified a new concept: SAR. SAR is a process whereby SA is improved after it has been degraded. SAR was characterized by more fixations, a longer resumption lag, fixations that were shorter in duration, more refixations, and fewer novel fixations.

These findings are consistent with the MFG model. The MFG model predicts that there will be increased resumption lag after an interruption due to the reactivation of decayed memory elements (Trafton et al., 2003). Although this prediction could not be explicitly tested in Experiment 1, in Experiment 2, resumption lag increased after an interruption. Additionally, the priming constraint of the MFG model states that an episodic code can be primed by contextual retrieval cues, in the present context, provided by the relevant stimulus objects (vehicles, hazards, targets; Altmann & Trafton, 2002; Ratwani, Andrews, Sousk, & Trafton, 2008). Consistent with this hypothesis, we found in both Experiment 1 and Experiment 2 increased scanning of previously viewed objects after an interruption, suggesting the use of priming as a strategy to regain SA. Such activity appears to represent a method to recover SA after the break.

How SA is recovered in a given context is likely related to the degree and nature of impairment to SA. We observed preferential looking at previously viewed objects during SAR, implying that participants retained some memory for those objects after the break but needed to reactivate their encoding of those objects. Consistent with this interpretation, the interruption did not interfere with lower-level perceptual SA, as assessed by the SAGAT questionnaire in Experiment 1, but only interfered with the comprehension stage of SA. Therefore, we examined SAR whereby participants retained some memory of the situation, so our findings may not generalize to situations in which SA is completely lost.

Another limitation of these experiments was that SA was evaluated only with the SAGAT in Experiment 1 and was evaluated only once at the end of each trial. However, the convention is to administer the SAGAT at random times during a trial. The reason that we administered the SAGAT at the end of each trial was to ensure that the SAGAT did not interfere with processing during the trial. However, we could infer that SA was reduced in Experiment 2 based on our findings from Experiment 1 and prior research regarding the disruptive effects of interruptions (Altmann & Gray, 2008; Monk et al., 2004; Ratwani et al., 2008; Trafton et al., 2003). Nonetheless, future research can include direct measures of SA throughout the task in order to directly identify how the amount of SA reduction affects the process of SAR.

An understanding of SAR can be used to mitigate operator errors, since errors are highly associated with reduced SA (Hartel et al. 1991). If situations in which the operator has low SA can be distinguished and the operator does not engage in SAR, these are instances in which the operator is more likely to make an error. Since not engaging in SAR when it is needed can result in increased errors, it may be useful to invoke adaptive automation in these instances. For example, participants can be cued to look at previously looked at objects in order to improve their SA through associative priming.

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KEY POINTS

- Situation awareness recovery (SAR) is the process of regaining situation awareness (SA) after the operator becomes distracted or following an interruption.
- The memory-for-goals model (Altmann & Trafton, 2002) makes specific predictions about how operators will engage in SAR: The priming constraint posits that cues in the environment will increase activation for degraded memory elements through spreading activation.
- The perceptual and cognitive processes involved in SAR include refixating on cues in the environment, increased resumption lag, increased scanning, and shorter-fixation durations. These results are highly consistent with the memory-for-goals theory.

REFERENCES

Altmann, E. M., & Gray, W. D. (2008). An integrated model of cognitive control in task switching. *Psychological Review*, *115*, 602–639.

Altmann, E. M., & Trafton, J. G. (2002). Memory for goals: An activation-based model. *Cognitive Science*, *26*, 39–83.

Altmann, E. M., & Trafton, J. G. (2004, August). Task interruption: Resumption lag and the role of cues. In *Proceedings of the 26th Annual Conference of the Cognitive Science Society* (pp. 42–47). Red Hook, NY: Curran Associates.

Altmann, E. M., & Trafton, J. G. (2007). Time course of recovery from task interruption: Data and a model. *Psychonomic Bulletin and Review*, *14*, 1079–1084.

Altmann, E. M., Trafton, J. G., & Hambrick, D. Z. (in press). Momentary interruptions can derail the train of thought. *Journal of Experimental Psychology: General*.

Anderson, J. R., Bothell, D., Byrne, M. D., Douglass, S., Lebiere, C., & Qin, Y. (2004). An integrated theory of the mind. *Psychological Review*, *111*, 1036–1060.

Boehm-Davis, D. A., & Remington, R. (2009). Reducing the disruptive effects of interruption: A cognitive framework for analyzing the costs and benefits of intervention strategies. *Accident Analysis & Prevention*, *41*, 1124–1129.

Boussemart, Y., & Cummings, M. L. (2008, September). *Behavioral recognition and prediction of an operator supervising multiple heterogeneous unmanned vehicles*. Paper presented at Humans Operating Unmanned Systems ’08, Brest, France.

Brondimonte, M., Einstein, G. O., & McDaniel, M. A. (Eds.). (1996). *Prospective memory: Theory and application*. Mahwah, NJ: Lawrence Erlbaum.

Crandall, J. W., Goodrich, M. A., Olsen, D. R., & Nielsen, C. W. (2005) Validating human-robot interaction schemes in multitasking environments. *IEEE Transactions on Systems, Man, and Cybernetics: Part A*, *35*, 438–449.

Durso, F. T., Truitt, T. R., Hackworth, C., Crutchfield, J., Nikolic, D., Moertl, P., . . . Manning, C. A. (1995). Expertise and chess: A pilot study comparing situation awareness methodologies. In D. J. Garland & M. R. Endsley (Eds.), *Experimental analysis and measurement of situation awareness* (pp. 295–304). Daytona Beach, FL: Embry-Riddle Aeronautical University Press.

Endsley, M. R. (1995a). Measurement of situation awareness in dynamic systems. *Human Factors*, *37*, 65–84.

Endsley, M. R. (1995b). Toward a theory of situation awareness in dynamic systems. *Human Factors*, *37*, 32–64.

Endsley, M. R. (2000). Direct measurement of situation awareness: Validity and use of SAGAT. In M. Endsley & D. J Garland (Eds.), *Situation awareness analysis and measurement* (pp. 113–128). Mahwah, NJ: Lawrence Erlbaum.

Endsley, M. R., & Rodgers, M. D. (1998). Distribution of attention, situation awareness and workload in a passive air traffic control task: Implications for operational errors and automation. *Air Traffic Control Quarterly*, *6*(1), 21–44.

Gugerty, L. J., & Tirre, W. C. (2000). Individual differences in situation awareness. In M. R. Endsley & D. J. Garland (Eds.), *Situation awareness analysis and measurement* (pp. 249–276). Mahwah, NJ: Lawrence Erlbaum.

Hartel, C. E. J., Smith, K., & Prince, C. (1991, April/May). *Defining aircrew coordination: Searching mishaps for meaning*. Paper presented at the 6th International Symposium on Aviation Psychology, Columbus, OH.

Hodgetts, H. M., & Jones, D. M. (2006). Contextual cues aid recovery from interruption: The role of associative activation. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *32*, 1120–1132.

Jones, D. G., & Endsley, M. R. (1996). Sources of situation awareness errors in aviation. *Aviation, Space and Environmental Medicine*, *67*, 507–512.

Kirlik, A., & Strauss, R. (2006). Situation awareness as judgment I: Statistical modeling and quantitative measurement. *International Journal of Industrial Ergonomics*, *36*, 464–474.

McFarlane, D. C. (2002). Comparison of four primary methods for coordinating the interruption of people in human-computer interaction. *Human-Computer Interaction*, *17*, 63–139.

Monk, C. A., Boehm-Davis, D. A., & Trafton, J. G. (2004). Recovering from interruptions: Implications for driver distraction research. *Human Factors*, *46*, 650–663.

Ratwani, R. M., Andrews, A. E., Sousk, J. D., & Trafton, J. G. (2008, September). *The effect of interruption modality on primary task resumption*. Paper presented at the Human Factors and Ergonomics Society 52nd Annual Meeting, New York, NY.

Ratwani, R. M., McCurry, J. M., & Trafton, J. G. (2008). Predicting postcompletion errors using eye movements. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 539–542). New York, NY: ACM.

Ratwani, R. M., & Trafton, J. G. (2011). A real-time eye tracking system for predicting postcompletion errors. *Human-Computer Interaction*, *26*, 205–245.

Salmon, P., Stanton, N., Walker, G., & Green, D. (2006). Situation awareness measurement: A review of applicability for C4i environments. *Applied Ergonomics*, *37*, 225–238.

Smith, K., & Hancock, P. A. (1995). Situation awareness is adaptive, externally directed consciousness. *Human Factors*, *37*, 137–148.

Sohn, Y. W., & Doane, S. M. (2004). Memory processes of flight situation awareness: Interactive roles of working memory capacity, long- term working memory, and expertise. *Human Factors*, *46*, 461–475.

St. John, M., & Smallman, H. S. (2008) Staying up to speed: Four design principles for maintaining and recovering situation awareness. *Journal of Cognitive Engineering and Decision Making*, *2*, 118–139.

Trafton, J. G., Altmann, E. M., Brock, D. P., & Mintz, F. E. (2003). Preparing to resume an interrupted task: Effects of prospective goal encoding and retrospective rehearsal. *International Journal of Human–Computer Studies*, *58*, 583–603.

Trafton, J. G., Altmann, E. M., & Ratwani, R. M. (2011). A memory for goals model of sequence errors. *Cognitive Systems Research*, *12*, 134–143.

Daniel Gartenberg is a PhD student at George Mason University. He received an MA in psychology from George Mason University in 2011.

Leonard Breslow is a cognitive scientist at Naval Research Laboratory. He received a PhD in psychology from University of California–Berkeley in 1981.

J. Malcolm McCurry is a research and programming contractor at ITT Exelis. He received a BA in psychology from George Mason University in 2005.

J. Greg Trafton is a section head for the Intelligent Systems Section at Naval Research Laboratory. He received a PhD in psychology from Princeton University in 1994.

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